

Primary Accretion in the Protoplanetary Nebula

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"Primitive" objects in the meteorite record represent the first large bodies to accumulate in the protoplanetary nebula—a vast data set that has had little context for interpretation. The accretion of primitive bodies almost certainly occurred in the presence of gas. Ames' efforts focus on numerical modeling of particle-gas interactions in turbulent flows, and understanding meteorite properties in the light of theoretical models.

A dense layer of particles orbiting in the midplane of a protoplanetary nebula at close to the unperturbed (or Keplerian) orbital rate generates a vertical velocity shear and associated turbulence, which prevents the particles from settling completely to the midplane and becoming gravitationally unstable (that is, from collapsing into planetesimals). However, it was thought possible that damping of the turbulence by the particles themselves might allow the particles to settle into an unstable layer. This year, a study was completed that modeled the evolution of such a layer that incorporated a new model for the damping effects of the particles on their self-generated turbulence. Although turbulence damping does flatten the layer, previously neglected terms were uncovered during the study that disperse the layer even more effectively, with the end result that the layer is even less flattened (more stable) than previously believed.

In prior years, Ames developed a hypothesis to explain the prevalence of millimeter-sized "chondrules" in chondritic meteorites by the mechanism of preferential concentration of aerodynamically selected particles in three-dimensional turbulence. The theory makes specific predictions as to the relative abundance distribution of the concentrated particles. To test the theory, four primitive chondritic meteorites were disaggregated, and the relative

distribution of particles was measured as a function of the product of their radius and density (the important determinants of the aerodynamic stopping time of the particles). Comparisons of the theoretical predictions (open symbols) and meteorite data (filled symbols) are shown in figure 1 for these four meteorites. Relative abundances are plotted as functions of the Stokes number (St), or ratio of particle stopping time to Kolmogorov eddy time. It has been realized for several years that the concentration is maximized for particles with $St = 1$, but not that the distribution function was so narrow.

A multifractal theory was developed to predict the magnitude of turbulent concentration at much higher Reynolds numbers than achievable numerically. The concentration is so large that mass loading (the feedback effect of the particle phase on the gas turbulence itself) must be considered before further modeling efforts can proceed. This theory might be of interest to terrestrial cloud modelers as well.

The prevalence of chondrules in meteorites (up to 80% in some classes) implies that they were pervasive in the nebula. Mineralogical studies imply that the favored melting process occurred on short time scales, over limited spatial scales, and in a relatively cool environment. Lightning, often observed in dry turbulent environments on the Earth, has been studied before and rejected by others. This study combined two new insights: the ability of "triboelectric charging" due to collisions between chemically dissimilar grains (large silicate chondrules and fine metal grains) to produce large positive charges on the silicate chondrules, and the ability of turbulent concentration to concentrate the charged chondrules and build up sufficient voltage to initiate large lightning strokes. Nebula lightning might also have implications for protoplanetary nebula chemistry.

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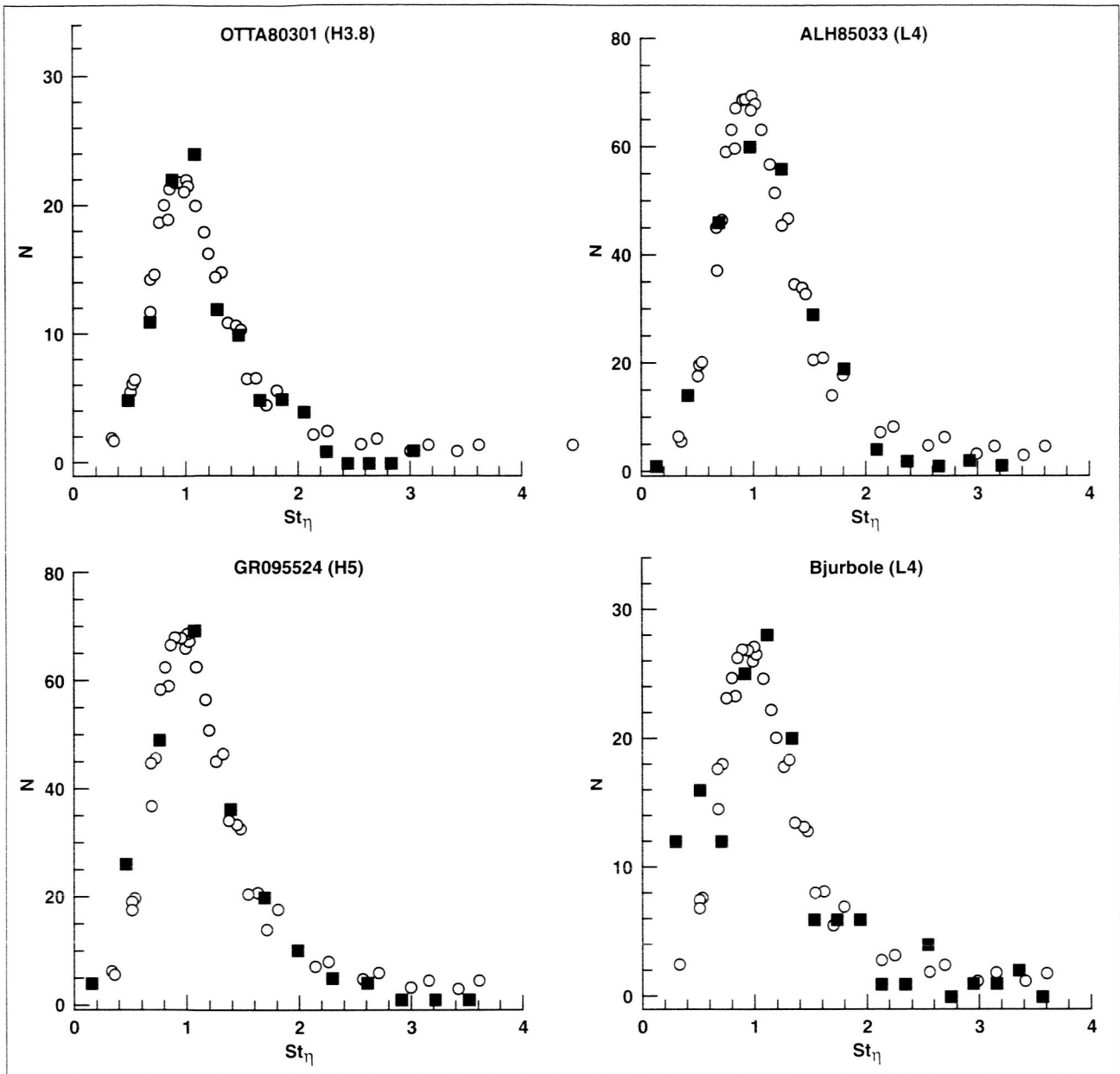


Fig. 1. Predicted (open symbols) and observed (filled symbols) distributions of particle size-density product as functions of their aerodynamic stopping time, as normalized to the Stokes number, St (subscripted here by the Kolmogorov scale), by dividing by the Kolmogorov eddy turnover time. The observed data are from four different primitive meteorite samples. The agreement is quite good. It was also found (not shown here) that using the actual density of each object rather than the average density of all objects noticeably improves the fit, as expected if aerodynamic sorting had operated to determine the chondrule size distribution.